

# **High-Frequency Scattering from Water Saturated Sandy Sediments: Laboratory Study**

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## **LONG-TERM GOALS**

The long-term goal of this research is to better understand the physics and mechanisms of sound-seabed interaction, including acoustic penetration, propagation, attenuation and scattering in marine sediments using a laboratory study approach.

## **OBJECTIVES**

The specific objective of this research is studying physics of interaction between high frequency sound and water saturated sandy sediments in well controlled laboratory conditions with a focus on effects of the sediment granular structure.

## **APPROACH**

Reported measurements of seabed scattering are largely confined to relatively low frequencies, up to 300 kHz, see, e.g., [Jackson and Richardson] and references therein. Still higher frequencies, up to a few megahertz, are used in seafloor imagery (e.g., in pencil-beam sonars), particularly to observe dynamic processes at the seafloor in shallow water. From the physics of sound-sediment interaction standpoint, however, interesting effects can be anticipated at these high frequencies, as the wavelength can become comparable with the sediment typical grain sizes. Unfortunately, existing observations in this case are usually non-calibrated and therefore do not allow measurements of system independent scattering characteristics of the seabed such as the bottom scattering strength.

Also, especially in shallow water, the dynamical complexity and unpredictability of environmental conditions can be so great that even very extensive time- and labor-consuming environmental measurements (such as those at SAX04, see, e.g., [Thorsos et al], and [Richardson et al]) may not be enough to sufficiently reduce the uncertainty in interpretation of acoustic data. In this connection, conducting experiments in well-controlled laboratory conditions can become a valuable (but much less expensive) supplement to the experiments at sea. An important advantage of laboratory studies of sediment scattering is that they make it possible to simplify the problem by reduction of the number of controlling parameters and allow observation of the effects of different scattering mechanisms separately. For example, the sediment can be degassed to eliminate effects of micro-bubbles, and its surface can be flattened to exclude contributions of the sediment roughness at scales greater than the grain size.

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In this research, experiments were conducted at the CNRS/LMA water tank facility on backscatter from sands over a wide frequency range, 150 kHz to 8 MHz. Note that existing methods for measuring the bottom scattering strength normally assume using narrow band signals (see, e.g., [Jackson and Richardson], pp.497-502). To be applied to broad-band transducers, significant modifications are required. One such modification was developed in the framework of this project. It made possible, to our knowledge for the first time, to measure and to analyze the frequency dependence of the sediment backscattering strength over such a wide frequency range. The analysis assumes that, for the given conditions, only one mechanism of scattering can be dominating, which is due to the sediment granular structure, and that the controlling sediment parameter is the mean grain size. In this case a scaling effect is possible: given grazing angle, the backscattering strength, which is system independent and depends only on frequency and sediment properties, can be presented as a unique function of only one parameter, the mean grain size/wavelength ratio. This effect was demonstrated and the scaling function was presented.

## **WORK COMPLETED**

Two kinds of water-saturated sediments with different grain sizes, moderately well sorted medium and coarse sands, were chosen for the study. Sediment properties such as the density, porosity and grain size, were measured by non acoustical methods. The medium sand had the mean grain diameter 0.245 mm, sediment/water density ratio 1.98 and porosity 36.5 %. The coarse sand had the mean grain diameter 1.55 mm, sediment/water density ratio 2.02 and porosity 33 %. Prior to the experiments, the two sediments were stored in containers filled with water treated with chlorine to exclude the presence of living organisms which might generate bubbles. The sediments were transferred in smaller containers (without exposure to air) to a large water tank (chlorine treated as well) where in addition they were sieved and agitated to eliminate remaining bubbles. After such preparations, the two sediments were placed in different plastic rectangular boxes of the same size with horizontal dimensions 17x23 cm and 9 cm in the vertical. The sediment surface was carefully flattened by scraping even with the box edges to eliminate roughness at scales larger than the sediment grains. Therefore, the necessary measures were taken to ensure that only the sediment granular structure be considered as a dominating mechanism (rather than large scale roughness and/or gas bubbles) controlling total scattering in and from the sediment.

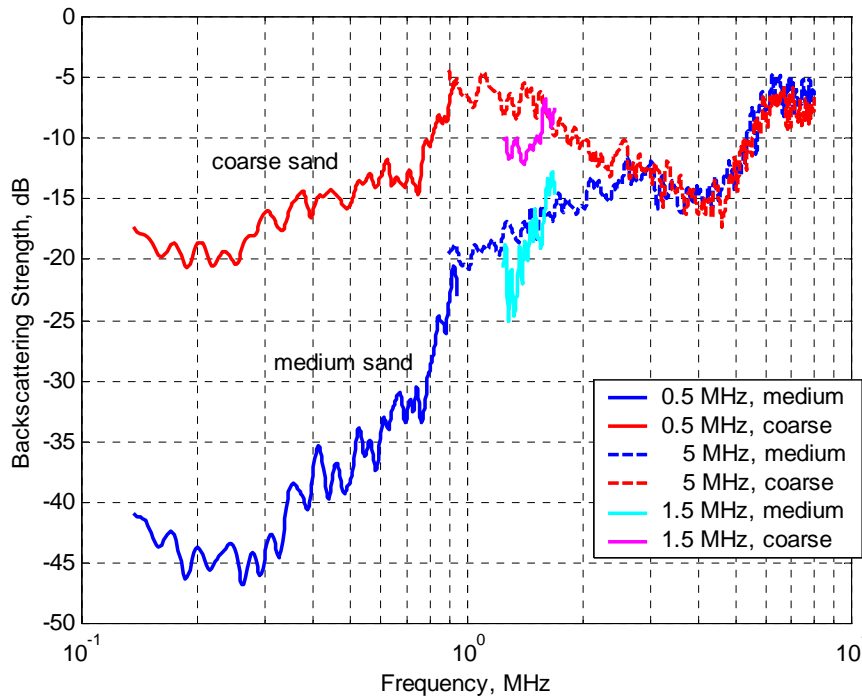
Experiments on backscattering from the sediments were conducted using a monostatic geometry with the transducers acting as both source and receiver (see, e.g., [Jackson and Richardson], Fig.G3). Two broadband Panametrics transducers with nominal center frequencies 500 kHz and 5 MHz were used, which, altogether, allowed covering continuously the wide frequency range of 150 kHz to 8 MHz. The transducers are circular pistons with radii 12.5 mm (500 kHz) and 6.5 mm (5 MHz). Their directivities are documented over all used frequencies and well described theoretically. The position of the transducers was controlled by a system allowing their automatic vertical and horizontal translation with 0.1 mm accuracy and their rotation with 0.1 degree accuracy. For calibration of each transducer, first the time series of the echo signal reflected from the water-air interface at normal incidence were measured and Fourier analyzed. Then, the transducer was rotated toward the sediment surface and set in a position with a fixed direction. Horizontal translations of the transducer (parallel to the sediment surface) were used to develop a statistically uniform ensemble of realizations for the echo signals. To provide the necessary statistics, a number of horizontal positions of the transducer was set automatically with a consecutive horizontal shift of 0.5 cm. At each position, time series of the echo

signal scattered from the sediment (at a fixed incidence angle) were measured for a number of pings (up to 64) and coherently averaged to reduce possible effects of noise.

Fourier spectral analysis was performed on the echo signals with a flexible time-windowing. The windowing was used, first, to reduce the effects of reverberation from the sediment box walls, and, second, to accommodate corresponding distances and the scattering areas of the sediment surface with the frequency dependent beam pattern of the transducer (as discussed below). The windowed echo frequency spectra were normalized by the spectra of the calibration signal. These normalized spectra provided a data set for the statistical processing. Particularly, their second moments (the squared magnitudes averaged over realizations), were used to obtain the frequency dependencies of the sediment backscattering coefficient and its decibel equivalent, the scattering strength.

## RESULTS

In Figure 1, the frequency dependence of the backscattering strength is presented in a wide frequency range, 150 kHz to 8 MHz, for the two sediments, medium and coarse sand, at an incidence angle of  $50^\circ$  (grazing angle of  $40^\circ$ ). It demonstrates, in particular, a noticeable difference in the scattering strength of the two sediments at frequencies below 2 MHz. For example, this difference at frequencies 400 kHz to 800 kHz is about 20 dB. It can mean practically important strong sensitivity of the

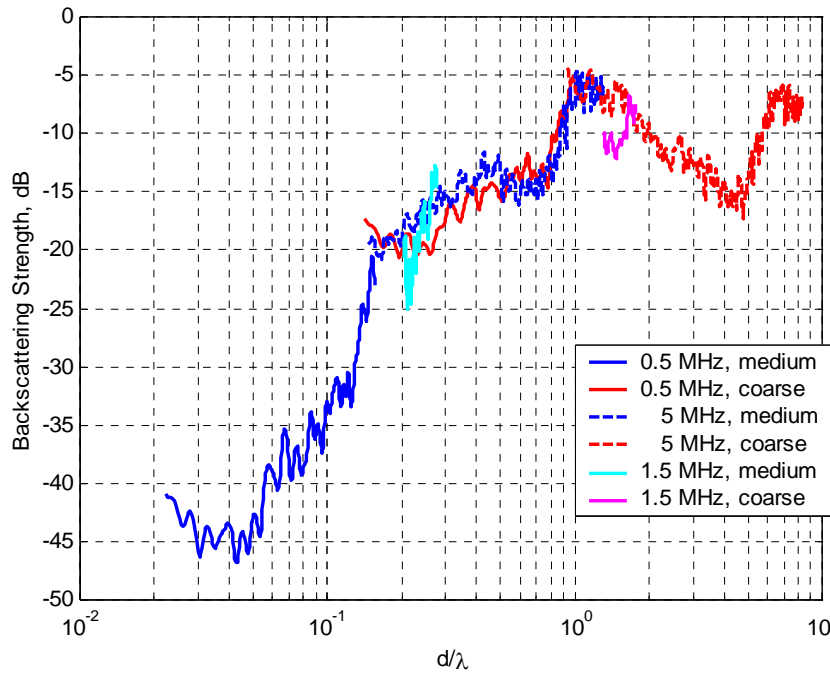


**Figure 1.** The backscattering strength at the incidence angle 50 degrees obtained for medium and coarse sand using the broad band transducers with 500 kHz and 5 MHz nominal center frequencies. The center frequency of the 500 kHz transducer was nominal indeed, as the transducer had actually another, although weaker, maximum in its frequency spectrum, at 1.5 MHz, which was used to obtain additional scattering data.

scattering strength at these frequencies to the mean grain size of the sediment. Note also that at frequencies above 2.5 MHz the difference is small and, therefore, the scattering strength may have too little sensitivity to the grain size.

The ratio of the mean grain diameter to the acoustic wavelength in water,  $d/\lambda$ , varied, in our frequency range, from 0.024 to 1.3 for the medium sand, and from 0.15 to 8.3 for the coarse sand. Therefore, in the interval  $0.15 < d/\lambda < 1.3$ , we have two data sets for sediments with different mean grain size. This interval is especially interesting as it corresponds to a “transition frequency regime”, where the acoustic properties of granular sediments can change dramatically. This change is due to transition from the “low frequency regime”, where the ratio  $d/\lambda$  is very small and the continuum media assumptions are valid, to the “very high frequency regime”, where this ratio is not small and the sediment must be considered as an essentially discrete granular medium. At these high frequencies, intrinsic (bulk) scattering due to the sediment granular structure becomes important. For example, the ratio  $d/\lambda$  becomes about 0.5 at frequencies around 3 MHz for the medium sand, and at 500 kHz for the coarse sand. Corresponding shift (for the sediments with different grain size) related to the “transition” effects and appearance of the new dominating scattering mechanism can be anticipated. In Figure 1, such a scaling shift is clearly seen.

In Figure 2, the scaling effect is demonstrated by plotting scattering data (same as in Figure 1) vs the ratio  $d/\lambda$ . It is seen that the backscattering strength collapses to a function of only one parameter, at least over the interval  $0.15 < d/\lambda < 1.3$  where both data sets are available. This confirms the assumption that, for the given conditions, only one mechanism of scattering is dominating, which is the intrinsic (bulk) scattering due to the sediment granular structure, and that the controlling sediment parameter is the mean grain size. In this case, the scattering strength must be a unique function of the ratio  $d/\lambda$ . This explains, e.g., that the two different grain-size cases match when shifted horizontally,



**Figure 2.** The same data as in Figure 1, but plotted vs the sediment mean grain diameter ratio to the wavelength in water,  $d/\lambda$ .

but no shift in the vertical is needed (see Figs. 1,2). This is because the scattering strength is unique, system independent and controlled only by the sediment parameters. It is practically important, as provides both prediction and inversion capabilities: if the scattering strength is measured at one frequency and one grain size, it can be predicted at others or inverted with respect to the grain sizes. Therefore, demonstrated here scaling effects potentially can be used in acoustic sensing of marine sediments to estimate their mean grain size remotely. Further analysis of these effects might be an interesting and promising subject of future theoretical and experimental studies.

## IMPACT/APPLICATIONS

The results on scattering from sediments obtained in this research will provide a better understanding of bottom acoustic interaction at high frequencies. Most results of this research has been published [1-4] or submitted for publication [5,6] and is widely open to scientific community. The original ideas and relationships between seabed physical properties (particularly the sediment mean grain size), and their scattering and reflection characteristics (such as the bottom backscattering strength and reflection coefficient) can be used in algorithms for remote geoacoustic characterization of marine sediments (ONR, Code 321CG).

## RELATED PROJECTS

This project is connected to other projects in the field of high frequency sediment acoustics and geoacoustics supported by the ONR-OA and ONR-CG programs. This work was conducted in collaboration with Dr. J.-P. Sessarego of LMA-CNRS.

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